Design and Analysis of Power Controller for Moving Magnet Linear Motor Compressor

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ABSTRACT

Permanent magnet linear motors (PMLM) are widely used in the design of pulse tube cryocoolers. In this paper, we discuss the design and analysis of a power controller used to drive the dual opposing piston type motors used in the pulse tube cryocoolers. The microcontroller dsPIC30F6010A drives two single phase H - bridge inverters which are used to drive both the motors. Pulse width modulated (PWM) technique is implemented to drive the inverter circuit. By varying the duty cycle of the PWM wave the voltage amplitude can be varied and the output frequency of the inverter can be varied by varying the carrier frequency of the PWM modulator. The phase difference between the two inverters can also be varied. This is used to synchronize the twin motors and overcome any existing phase difference due to the mechanical systems. Variation in performance of the PMLM caused by the variation in the applied voltage and frequency is illustrated.

Simple square PWM modulation, trapezoidal PWM modulation and sine PWM modulation techniques are implemented by controller programming. Motor performances for these modulation techniques are discussed. It is also shown that the current wave form contains less harmonic content in the case of sine modulation.

INTRODUCTION

Development of a power electronic drive for a linear motor of compressor was taken up as a part of project on the Development of Pulse Tube Cryocooler at the Indian Institute of Science, Bangalore, India. The compressor consists of two permanent magnet linear motors. A switched mode power supply is developed to drive linear motors which provides easy control of power flow to the motor. The digital controller for the power supply is developed using the microcontroller dsPIC30F6010A. The power control to the twin motor is achieved by varying the switching patterns of the MOSFET switches used in the power converters.

POWER DESIGN

The power supply consists of two single phase AC to DC converters and a digital controller. The single phase H bridge voltage source inverter is shown in the Figure 1 (a) and the schematics of inverter board is as shown in Figure 2. The inverter is designed using four N channel power

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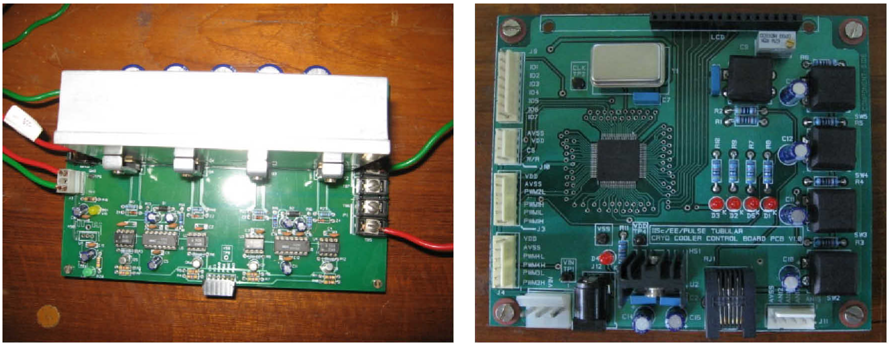


(a) (b)

Figure 1. (a) Inverter Board. (b) Digital Controller (dsPIC30F6010A).

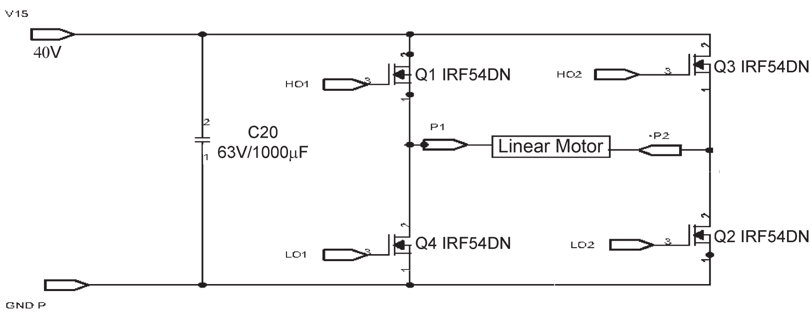


Figure 2. Schematics of inverter board. Linear motor connected to H-bridge of MOSFET.

MOSFETs. The inverter is rated for 100 W, 5 A. The output voltage of the inverter is controlled using the pulse width modulation (PWM) technique. The MOSFETs are turned on and off at high frequency in each half cycle and the inverter output voltage is varied by varying the duty cycle of the gate pulse. The output voltage of the inverter is a square wave with high frequency switching but the current waveform does not contain these high frequency components as the motor inductance acts as a low pass filter.

CONTROLLER DESIGN

The PWM signals are generated with the digital controller. The digital controller is designed using microcontroller dsPIC30F6010A as shown in Figure 1 (b) and the schematics of controller board is shown in Figure 3. The microcontroller has a built in PWM module. Four PWM signals are generated along with their complements which are used to drive the gates of the MOSFETs of two inverters. The PWM patterns used to drive the MOSFET gates are generated by comparing a high frequency saw tooth wave with an appropriate modulating signal. The schematics of the gate circuit is as shown in Figure 4. This is implemented in the controller using counters and comparators of the PWM module. Sufficient dead time is provided between the ON state MOSFET, switch to turn off and OFF state MOSFET, switch to turn ON, so that the positive rail of the inverter is not short circuited with negative rail.

MODULATION TECHNIQUES

The harmonic content of the output current can be reduced by using different pulse width modulation techniques. The inverter is driven using simple square modulation, trapezoidal modulation and sine modulation techniques. The modulating techniques are implemented by programming

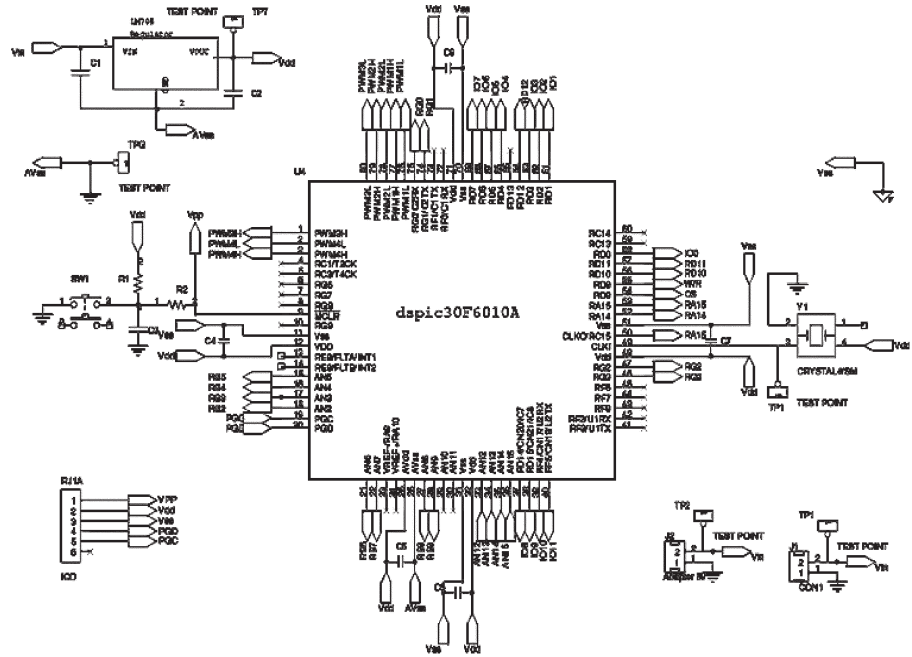


Figure 3. Schematics of dsPIC30F6010A controller board which generates PWM waves.

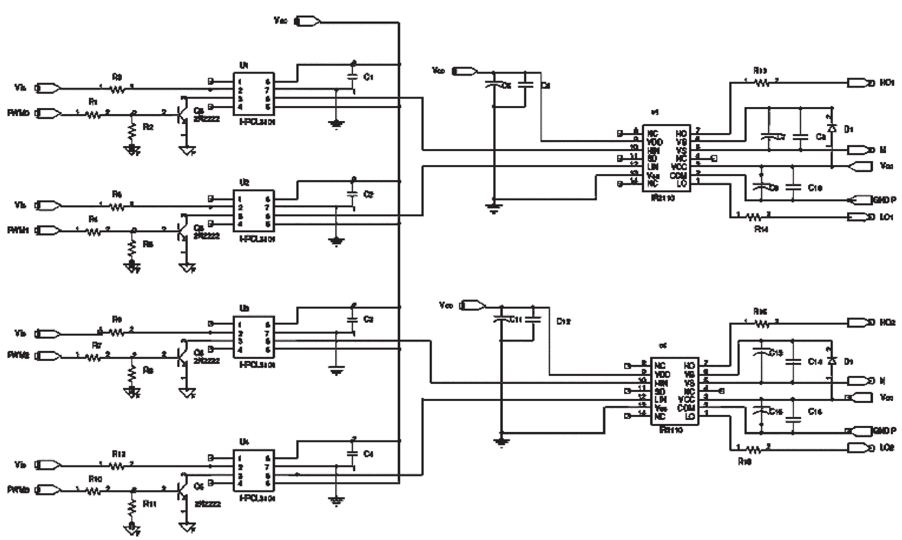


Figure 4. Schematics of gate drive circuit. The controller output PWM pulses are fed to gate drive circuit which in turn drives the MOSFET of inverter board connected to linear motor.

the controller to vary the reference modulating signal as a square wave, trapezoidal wave or a sinusoidal wave, respectively.

The eddy current loss in the permanent magnet linear motor is proportional to the square of the frequency[1,2]. Higher frequency harmonic content would lead to excess core losses, heating the material which leads to deterioration of the NdFeB magnets, hence it is important to suppress the higher harmonic contents in the input current to the motor. As the motor inductance acts as a low pass filter to the input current, most of the higher order harmonics get filtered out.

In Figure 5 (a), (b) and (c), the motor displacement waveform, input current wave form and the FFT of the input current waveform are shown one below the other in each figure for simple square, trapezoidal and sine modulation respectively. It is observed from Figure 5(a), that all the odd harmonic contents are present in the case of simple square modulation. In the case of trapezoidal modulation, Figure 5(b), though higher order components are eliminated third and fifth order harmonic contents are seen. In the case of sine modulation Figure 5(c), very low third harmonic content is seen and higher harmonics are eliminated. Even harmonics are absent as the positive half of the waveform is the reflection of the negative half.

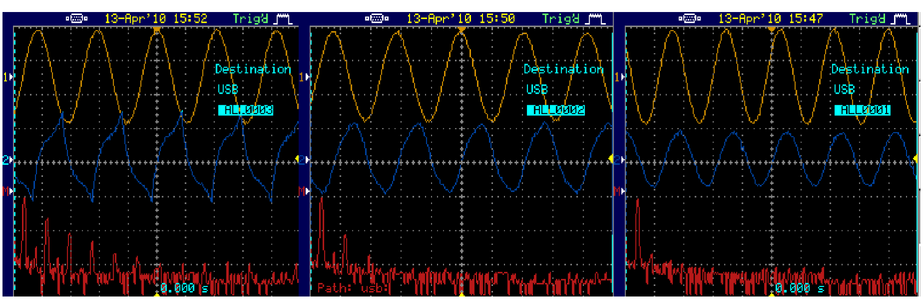
FREQUENCY OPTIMIZATION

The controller is designed with four push buttons. The inverter output frequency, voltage and the phase difference between the two inverter output voltages can be manually varied using the push buttons. The output frequency is varied by varying the frequency of the modulating signal. The power consumption of the motor is dependent on the frequency and consumes less power at the resonant frequency. At atmospheric pressure, it was found that the motor consumes least power at fifty four hertz. Under higher pressure this frequency would vary and can be found and adjusted using the controller. Figure 6 shows the power versus frequency graph for the two motors of the compressor. The small phase difference between the displacements of the two motors can be nullified electrically by varying the phase difference between the power controller outputs.

CONCLUSION

In this paper, the design of a variable frequency voltage source inverter to drive linear motor of compressor is discussed. The following contributions have been made in this paper:

1. Development of switched mode power supply for the linear motor.
2. Implementation of simple square PWM, trapezoidal PWM, and sine PWM for voltage source inverter. It was observed that for sine PWM the harmonic contents are very less.
3. Variable frequency operation is implemented and frequency optimization is made.



(a) (b) (c)

Figure 5. Motor displacement, current and FFT of current waveform for (a) Simple square modulation, (b) Trapezoidal modulation (c) Sine modulation.

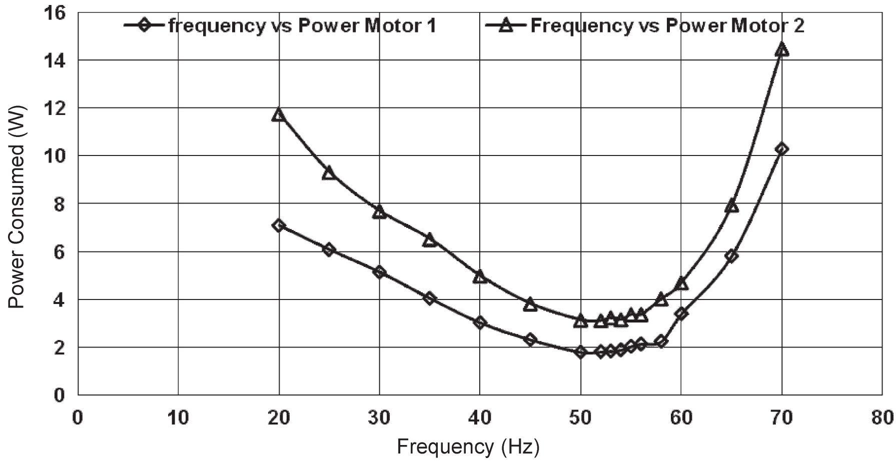


Figure 6. Power versus frequency curve. Minimum power is drawn at 54 Hz at atmospheric pressure.

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